

# PATENT SPECIFICATION

DRAWINGS ATTACHED

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## COMPLETE SPECIFICATION

### Helicopter Rotor Correction Mechanism

We, THE KAMAN AIRCRAFT CORPORATION, a Corporation organized under the Laws of the State of Connecticut, United States of America, of Old Windsor Road, Bloomfield, Connecticut, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

Desirably each blade of a multi-bladed helicopter rotor is exactly like each other blade, and when this is so each blade during each rotor rotation has exactly the same action as each other blade, both as to forces encountered and applied and as to path of movement. However, the blades may unavoidably have minor physical differences in shape or in material or in mounting, and when there are such physical differences the blades may have differences in action or function. The rotor may have an unbalance usually resulting from a difference in lift between one blade and another and the unbalance gives rise to an undesirable vibration. The unbalance or lift difference ordinarily results in differences in the paths of movement of the blade tips. A common procedure for at least approximately correcting unbalance or lift difference has been to merely make whatever blade adjustments were necessary to bring about uniform paths of blade tip movement, this ordinarily being referred to as "blade tracking".

In its broader aspects the invention is applicable to a helicopter of any type, but in its more specific aspects the invention is particularly adapted for use in a helicopter of the type disclosed in British Specification No. 676,398.

The general object of the invention is to provide a mechanism or device controlled from the fuselage for adjusting a selected blade of a helicopter rotor so that unbalance is cor-

rected with all of the blades of the rotor ordinarily "in-track", said unbalance correcting mechanism being simple and reliable and being operable at least during rotor rotation.

A more specific object of the invention is to provide an unbalance correcting means for the purpose stated wherein the blades of the rotor are movable relatively to the rotor hub about substantially vertical lead-lag axes and wherein the correcting mechanism connected with the selected blade is also movable relatively to said hub about the corresponding lead-lag axis.

Another more specific object of the invention is to provide a means for the purpose stated which includes an electrically operated unbalance correcting mechanism carried by the rotor and rotatable therewith and which further includes devices on the fuselage for controlling said rotatable electrically operated mechanism.

Still another more specific object of the invention is to provide a means for the purpose stated which is particularly adapted for use in or as a part of a helicopter of the particular type disclosed in said Specification No. 676,398.

Other objects of the invention will be apparent from the drawings and from the following description and claims.

In the drawings we have shown in detail two embodiments of the invention, but it will be understood that various changes may be made from the construction shown, and that the drawings are not to be construed as defining or limiting the scope of the invention, the claims forming a part of this specification being relied upon for that purpose.

Of the accompanying drawings:—

Fig. 1 is a perspective view of the upper portion of a helicopter having two rotors and adapted for the incorporation of the present invention therein.

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Fig. 2 is an enlarged plan view of a portion of one of the rotors shown in Fig. 1.

Fig. 3 is a transverse sectional view taken along the line 3—3 of Fig. 2.

5 Fig. 4 is a fragmentary side view of the rotor shown in Fig. 2.

Fig. 5 is an enlarged vertical sectional view taken along the line 5—5 of Fig. 4.

10 Fig. 6 is an enlarged fragmentary combined side and sectional view of a portion of the unbalance correcting mechanism as shown in Fig. 4, the left sectional portion of this view being taken along the line 6—6 of Fig. 5.

15 Fig. 7 is a combined plan and horizontal sectional view taken along the line 7—7 of Fig. 6.

Fig. 8 is a fragmentary vertical sectional view taken along the line 8—8 of Fig. 7.

20 Fig. 9 is a vertical sectional view taken along the line 9—9 of Fig. 7.

Fig. 10 is a fragmentary horizontal sectional view taken along the line 10—10 of Fig. 9.

25 Fig. 11 is a diagram of electrical connections.

Fig. 12 is a schematic fragmentary perspective view showing a mechanism embodying the invention applied to a helicopter of a type different from that shown in Figs. 1 to 4.

30 Fig. 13 is a plan view of a portion of the mechanism shown in Fig. 12.

Fig. 14 is an end view of a portion of the mechanism shown in Fig. 13.

35 The invention as to certain aspects thereof is of general applicability, but as to other aspects it is particularly adapted for a helicopter of the type disclosed in said Specification No. 676,398. The invention will be first described as applied to a helicopter of said type. Fig. 1 is a view showing a portion of such a helicopter, said view being taken from the left of the helicopter and toward the rear, Figs. 2, 3 and 4 show in greater detail one of the rotors of said helicopter. Reference is made to said Specification No. 676,398 for a more complete disclosure of any details not herein fully disclosed.

40 The helicopter, as shown, comprises a fuselage 10 and left and right rotors 11 and 12 which are connected with left and right supporting and driving shafts 14 and 15. Said shafts extend upwardly from said fuselage 10 and as shown they are spaced apart transversely and they diverge upwardly. The said shafts are interconnected for rotation in unison and in opposite directions. Each rotor preferably has two opposite blades and said rotors are so connected with the shafts that their blades 16, 17 and 18, 19 are in intermeshing relationship. While the shafts 14 and 15 diverge and are not exactly vertical, said shafts and their axes of rotation will, for convenience, be sometimes referred to as being substantially vertical.

65 Each blade of each rotor is connected with

the corresponding shaft for movement about a substantially horizontal axis extending transversely of the blade. Preferably and as shown, the two blades of each rotor are connected with a common hub member so as to be in fixed relationship therewith except for lead-lag movements, as hereinafter explained, and the blades and hub are adapted for oscillation in unison about a common transverse pivotal or teeter axis.

70 In order that the manner of operation of the hereinafter described unbalance correcting means may be fully understood, one rotor and the pitch changing mechanism therefor, and more particularly for one blade thereof, will be fully described. Extending through horizontal apertures in the upper part of the shaft 14 is a horizontal pivot or teetering pin 20 which serves to pivotally connect the hub member and its blades with the shaft, said hub member being designated 22 and having a large central aperture through which the upper end of the shaft extends. The teetering pin 20 is so located with respect to the hub member that the axis of pivotal movement of said hub member is at an acute angle, preferably about 60°, with respect to the longitudinal axes of the blades 16 and 17. The said angle is such that each end of the pivot pin 20 is at the leading side of the longitudinal axis of the corresponding blade.

75 Two blade supports 24 and 25 are provided at the ends of the hub member 22, these blade supports being connected with the hub member by means of vertical lead-lag hinge pins 26 and 27 for pivotal movement about vertical lead-lag axes. Said hinge pins are fixed to the respective blade supports and they are movable relatively to the hub member. The inner end or root portions of the blades 16 and 17 are connected with the respective blade supports. Shoulders on the hub member 22 limit relative movement of the blade supports and the blades in either direction with respect to the hub member. In order that the two blade supports with their corresponding blades may move substantially in unison about the axes at 26 and 27, said blade supports are interconnected by link means 28 and 29, each of the said link means being variable in length and including a damper which resists variations in length. As shown, the dampers in the said link means act frictionally, but hydraulic dampers may be substituted if desired. The said link means 28 and 29 with the dampers therein resist any pivotal or oscillatory movement of one blade support with its blade about the corresponding lag axis independently of the other, but the said means nevertheless permit such independent pivotal or oscillatory movements to limited extents. For more clearly showing other parts, the link 29 is omitted from Fig. 4.

125 As has been described, the two blades are

preferably pivotally movable in unison about the substantially horizontal teetering axis of the pin 20 and they are also pivotally movable about the substantially vertical lead-lag axes 26 and 27. In addition, the blades are adjustable about substantially radial axes extending longitudinally of the blades for the purpose of changes of pitch. Preferably the outer end portions of the blades respectively carry auxiliary aerofoil flaps 30 and 31 which are angularly movable relatively to the blades about axes substantially parallel with said longitudinal axes of the blades. Each flap 30 or 31 may be adjusted angularly about the corresponding said longitudinal axis by relatively movable flap moving connections extending from the flaps to the fuselage. When the blades 16 and 17 are rotating, the flaps 30 and 31 serve by reason of aerodynamic forces acting thereon to adjust the corresponding blades and to thus change the effective pitches of the blades. The extent of the changes in the effective pitches of the blades is dependent upon the angular positions of the flaps as determined by their before-mentioned flap moving connections.

The blades are shown as being rigidly held at their inner ends or root portions so as to prevent any relative rotative movement of said root portions about axes extending longitudinally of the blades. Each blade is initially positioned as shown in Figs. 2 and 3, but said blade is capable of substantial twisting about its longitudinal main axis and with respect to its non-rotatable root portion so that its effective pitch is changed as the result of the twisting. The blade has torsional resiliency which tends to restore it to its initial normal position and shape after twisting. The before-described flaps 30 and 31 serve aerodynamically to twist the blades and thus change the pitches thereof.

The mounting means and the flap moving connections for one flap, that is, the flap 30, are shown in detail in Figs. 2, 3 and 4. A bracket 32 is provided for pivotally connecting each flap such as 30 with the corresponding blade 16, and the bracket preferably fits around the blade. Secured to the flap 30 is a bracket 34 and this bracket is connected with the bracket 32 for pivotal movement about an axis at 36 substantially parallel with the mean axis of the blade.

The aforesaid flap moving connections include a link or rod 38 which is located within the hollow shaft 14 and is movable vertically. A similar rod 40 is provided for the flap 31 on the blade 17. The connections between the rods 38 and 40 and the corresponding flaps are similar and it will be sufficient to describe in detail the connection between the rod 38 and the flap 30.

The rod 38 is connected at its upper end with one arm of a bell crank 44 which is pivoted at 46 on the hub member 22 for

movement about a horizontal axis which is perpendicular to the longitudinal axis of the blades when the corresponding blade is in the position shown. The other arm of the bell crank 44 is connected at 48 with one end of a link 50, the connection being such that the link can swing laterally as well as vertically. The opposite end of the link 50 is connected at 52 with a lever 54, the connection being such as to accommodate horizontal swinging of the link. As shown in Fig. 5, the lever 54 has an inverted U-shape and is pivotally connected to the blade support 24 for movement about a horizontal pivotal axis 56 extending transversely of the blade. A second lever 58 is pivoted to the blade support 24 for movement about a horizontal axis at 60 also extending transversely of the blade. The two levers 54 and 58 are connected by a link 61. A push-pull link or rod 62 extends longitudinally of the blade 16 along the leading edge thereof, the inner end of the link being pivotally connected with the lever 58 at 64. The outer end of the rod 62 is pivotally connected at 65 with one arm of a bell crank 66 which is pivotally connected with the bracket 32 for rotation about a vertical axis at 68. A link 70 is pivotally connected at its forward end at 72 with the other arm of the bell crank 66. The rearward end of the link 70 is pivotally connected at 74 with an extension formed integrally with the bracket 34 which carries the flap 30.

Aerodynamic action on the flaps 30 and 31 during rotor rotation serves to apply downward forces or upward forces to the trailing portions of the blades 16 and 17, the direction of said forces being dependent upon the aerofoil shape and the angular positions of the flaps. For normal flight, each flap is moved relatively clockwise from the Fig. 3 position so that it has a negative effective pitch, and aerodynamic action on the flap during rotation serves to apply a downward force at the trailing portion of the corresponding blade. This downward force twists the blade in the counterclockwise direction to increase the positive pitch thereof, and the increased positive pitch tends to flex the entire blade upwardly with respect to its relatively fixed root portion. The aforesaid negative pitch of the flap tends to flex the entire blade downwardly in opposition to the upward flexing caused by blade pitch. The downward flexing tendency resulting from the flap pitch is relatively small, and the upward flexing tendency prevails over the downward flexing tendency. When the flap is moved relatively counterclockwise to decrease the negative pitch thereof, there is a reversed or clockwise twisting of the blade with a resultant decreased positive blade pitch. As the result of the decreased blade pitch there is a decreased tendency for the entire blade to be flexed upwardly.

From the foregoing description of the flap action it will be apparent that, for each blade, the amount of blade twisting and the resultant amount of blade flexing are dependent upon the relative angular position of the corresponding flap as determined by the corresponding flap moving connections which include the rod 38 or the rod 40. Referring particularly to the flap 30 and the connections therefor, it will be observed that when the rod 38 is moved upwardly, the bell crank 44 is moved counterclockwise and the levers 54 and 58 are swung outwardly and the push-pull rod 62 is moved outwardly. Outward movement of the rod 62 causes rearward movement of the link 70, thus moving the flap 30 upwardly or clockwise to increase the negative flap pitch and to thus increase the positive pitch of the blade and the upward flexing thereof. When the rod 38 is moved downwardly, the described movements are reversed and the flap 30 is moved downwardly or counterclockwise to decrease the negative flap pitch and to thus decrease the positive pitch of the blade and the upward flexing thereof.

The rods 38 and 40 for the flaps 30 and 31 on the two blades of the rotor are connected with suitable means in the fuselage for moving them vertically to change the blade pitches in the manner described. By means of said rods the blade pitches may be changed collectively or cyclically, all as fully explained in said Specification No. 676,398. The two rods are moved upwardly or downwardly in unison and to uniform extents for collective changes in pitch and they are moved upwardly or downwardly separately and to uniform extents for cyclic changes in pitch.

For effecting the correction of rotor unbalance any one of the blades of the rotor is arbitrarily chosen as the master blade, and the other blades are adjusted with reference to the master blade so that the blades are balanced and ordinarily so that the tips of all of the blades move in the same path or at least substantially in the same pitch. For a two-bladed rotor it is only necessary to adjust one blade. It is recognized that, even with the blades of a helicopter rotor in balance, the tips of said blades do not move in simple circular paths in a single plane. On the contrary, the path of movement of each blade tip is quite complex, being determined by various factors, such as the tilting or teetering of the rotor about the axis 20 during each revolution, and the cyclical changing of the blade pitches. However, notwithstanding path complexity, the path for each blade tip under normal conditions should always be the same as that for each other blade.

In accordance with the invention, the helicopter comprises a rotor which includes at least two similar blades each having its inner

portion connected with said shaft for movement about a substantially horizontal transverse axis and the helicopter also comprises devices controlled from the fuselage for changing the pitches of all of the rotor blades during rotation in accordance with flight requirements and the helicopter further therewith comprises a mechanism carried by the rotor for rotation therewith and adapted for correcting rotor unbalance which mechanism is connected with a selected blade of said rotor and is operable during rotor rotation for adjusting said selected blade to change the lift thereof relatively to that of each other blade while otherwise maintaining the pitches required for flight, and the helicopter further comprises control means for said correcting mechanism connected therewith but carried by said fuselage independently of said rotor.

More specifically and in accordance with the invention, said rotor of the helicopter includes a hub to which the blades are pivotally connected for movement about substantially vertical lead-lag axes. When the rotor is constructed as last above stated, the mechanism for correcting rotor unbalance is mounted and connected not only for rotation with the hub but also for relative oscillation with one of the blades about the corresponding lead-lag axis.

Still more specifically and in accordance with the invention, said rotor of the helicopter includes a hub pivoted to the shaft for oscillation about a substantially horizontal teeter axis and also includes two opposite similar blades each having its inner portion so connected with the hub as to prevent relative movement about a horizontal axis. When the rotor is constructed as last stated, the mechanism for correcting rotor unbalance is carried by the hub of said rotor not only for rotation therewith but also for oscillation therewith.

As illustrated, the blade 17 is the chosen master and the blade 16 has been selected for adjustment so as to compensate for any variation from the master blade as to lift or as to balance or as to tracking of the blade tip. Preferably and as shown, the selected blade 16 is adjusted relatively upwardly or downwardly as required, by adjusting the flap 30 on said blade 16 without any corresponding adjustment of the flap 31 on the blade 17. If the blade 16 is too low, the flap 30 thereon is separately moved clockwise so as to separately increase the pitch of said blade and thus increase the upward flexing thereof. If the blade 18 is too high, the flap 30 thereon is separately moved counterclockwise so as to separately decrease the pitch of said blade and thus decrease the upward flexing thereof.

The separate movement of the flap 30 on the blade 18 is effected by relatively adjusting a portion of the flap moving connection, without impairing the effectiveness of said

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connection for normally moving the flap. Preferably and as shown, the required adjustment is made by moving a pivot pin 75 which provides the pivotal axis 56 for the lever 54. As best shown in Figs. 5 and 6, the pin 75 is supported by a sleeve 76 which is carried by the corresponding blade support 24. The pin projects beyond the ends of the sleeve and the legs of the U-shaped lever 54 are mounted on the ends of the pin by means of bearings 78, 78. The sleeve 76 has integral eccentrics 80, 80 which fit bearing apertures in the blade support 24. The sleeve 76 also has an integral arm 82 which extends downwardly and is connected with a link 84. By means of the link 84 the sleeve 76 can be turned and by reason of its eccentric mounting it serves to bodily move the pivot pin 75 and the pivotal axis 56 toward the right or toward the left as viewed in Figs. 4 and 6. When the pin is moved toward the right, the rod 62 is moved toward the right and the negative pitch of the flap 30 is decreased and the upward flexing of the blade 16 is decreased. When the pin is moved toward the left, the rod 62 is moved toward the left and the negative pitch of the flap 30 is increased and the upward flexing of the blade 16 is increased. It will be obvious that the described movement of the pin 75 does not in any way affect the normal control of the flap and of the blade pitch by the described linkage.

For moving the link 84 and for thus correcting unbalance or lift differences as explained, there is provided a mechanism, which is indicated generally by 85, carried by and rotatable with the rotor and which is adapted to be operated or controlled by non-rotatable means in the fuselage. As to details, said mechanism 85 can be widely varied, but one mechanism having certain advantageous features is shown and this mechanism will be particularly described, said mechanism being shown in Figs. 6 to 10.

The mechanism 85 is movable with the blade 16 about the corresponding lead-lag hinge axis. Preferably and as shown, said mechanism 85 is carried directly by the corresponding lead-lag hinge pin 26. The mechanism 85 is shown as comprising a rotary electrical actuator unit 86, a gearing unit 88, and a pivoted arm 90 carried by the unit 88 and connected with the link 84. The two units 86 and 88 are rigidly connected with each other. Inasmuch as the mechanism is mounted eccentrically of the axis of rotor rotation, a suitable counterweight, not shown, may be provided.

The specific connection with the lead-lag hinge pin 26 is best shown in Fig. 8. A vertical pin 92 is provided which is, in effect, a downward extension of the lead-lag hinge pin. The pin 92 has a head 94 which fits within the central opening of the lead-lag

hinge pin. A transverse pin 95 locks the pin 92 in place. A nut 96 engages the threaded lower end of the hinge pin 26 to hold it in place, a washer 97 being interposed between the nut and the bottom of the hub 22. Said pin 92 extends downwardly through holes in the housing of the actuator unit 86 and is provided at the bottom with a nut 98. Said nut 98 holds said actuator unit and the entire mechanism in fixed position with respect to said pin 92 and thus in fixed position with respect to the lead-lag hinge pin 26. As before stated, the hinge pin is fixed to the corresponding blade support, and it will therefore be apparent that the unit 88 and the parts carried thereby are in fixed relationship with the blade support.

The actuator unit 86 comprises a rotor 100 which includes a longitudinal shaft, only said shaft being shown in the drawings. Said shaft of the rotor has a pinion 101 at its outer end, as shown in Figs. 7 and 10. The pinion 101 meshes with a gear 102 on a longitudinal shaft 104 mounted in the gearing unit and extending into the actuator unit. The shaft 104 carries a worm 105 which meshes with a worm wheel 108 on a transverse shaft 110 mounted in bearings 112 and 114. The shaft 110 projects at the rear or at the left as viewed in Fig. 9, and said arm 90 is secured to the projecting end of said shaft.

Preferably a switch box 116 is mounted on the end face of the unit 88 and a switch 118 in said box is operated by the shaft 104, the switch being shown only in Fig. 11. The function of said switch 118 will be hereinafter described in connection with Fig. 11. The housing of the gearing unit preferably has a transverse hole 120 communicating with a longitudinal hole 122 extending to the actuating unit. These holes are for electrical wires which for convenience of illustration are omitted from Figs. 6 to 10.

Current for operating the rotary actuator and for other purposes is supplied through a cable 124 connected with rotary slip rings 126 which are insulated from each other and are carried by the rotor shaft 14. A non-rotary structure 128 is provided adjacent the shaft and brushes 130 on said structure engage and provide electrical connection with said slip rings.

The rotary actuator of the unit 86 does not of itself constitute any part of the present invention and the actuator is or may be of a known type. The actuator has a shiftable or rotatable field, and as shown in Fig. 11 this field is controlled by the current in three conductors 132 which revolve with the hub and are included in the cable 124, the wires serving to rotate the field of the actuator and to cause the rotor thereof to correspondingly rotate. The movable conductors 132

are connected through the slip rings 126 and the brushes 130 with nonrotary conductors 134. The conductors 134 are connected with means on the fuselage 10, such as a step switch 136 for supplying current to the actuator in such a manner as to rotate the field thereof.

The specific step switch 136 and the specific actuator of the controlled unit 86 do not constitute a part of the present invention, such switch and actuator being of conventional construction. Said step switch 136 includes a rotatable element and in accordance with recognized practice the construction and connections of the switch 136 and of the actuator are such that the current transmitted to the actuator through the described conductors serves to turn the rotor 100 of the actuator in unison with the turning of the rotatable element of the switch 136. Inasmuch as the switch and the actuator are of known types, as before stated, no detailed description is necessary.

While the invention is not so limited, the step switch 136 is shown as being manually operable by a rotatable handle 138 on a shaft 140. The switch 136 is connectable with the main lead 142 by a normally open switch 144. When manually controlled tracking is to be effected, the pilot moves the handle 138 longitudinally of the shaft to close the switch 144 and thus connect the switch 136. Then the pilot turns the handle 138 in one direction or the other and the step switch 136 causes the rotor 100 of the actuator to turn at the same speed as the handle.

The handle 138 and the parts operated thereby including the switch 136 constitute control means for the mechanism 85 for correcting unbalance, said control means being carried by the fuselage 10 independently of the rotor 11. The conductors 134 and the slip rings 126 and the conductors 132 included in the cable 124 constitute means operatively connecting said control means on the fuselage with said correcting mechanism 85 on the rotor for enabling said control means to control the operation of said correcting mechanism during rotation of said rotor.

The before-mentioned switch 118 is preferably provided, and when provided it is connected with a conductor 146 in said cable 124. The conductor 146 is connected through one of said slip rings 126 with a conductor 148 which in turn is connected with an indicator light 150. The construction and manner of connection of the switch 118 are such that the switch is open when the correcting mechanism is in any intermediate position of adjustment. However, the switch is closed whenever said mechanism approaches either of its limits of adjustment. The closing of the switch causes the lighting of the indicator light 150 with resulting warning to

the pilot that a limit of correcting adjustment is being approached.

When the helicopter has two rotors such as 10 and 12, it is necessary to provide two unbalance correcting mechanisms, one for each rotor. The parts and connections shown in Fig. 11 may be regarded as being for the rotor 10. Duplicate parts and connections are provided for the rotor 12.

It has been herein previously stated that the present invention is not limited for use in a helicopter of the type disclosed in said Specification No. 676,398. In order that this fact may be more clearly evident, a helicopter of a different type is fragmentarily and schematically disclosed in Figs. 12, 13 and 14, said last-mentioned helicopter having a single three-bladed rotor.

Referring to Figs. 12, 13 and 14, the rotor of the helicopter includes a hub 152 having three arms 154, 156 and 158 equally spaced circumaxially and each having similar upper and lower sections and each carrying a rotor blade. The blade and the connections therefor are the same for the said three arms, and only one blade 160 and its connections are shown. The arm 158 has a lead-lag hinge pin extending between the upper and lower sections thereof and having a vertical axis at 162. A trunnion block 164 is pivotally mounted on said lead-lag hinge pin between said sections of the arm 158. A yoke 166 embraces said trunnion block and is connected therewith for movement about a horizontal flapping axis 168 preferably intersecting the vertical lag axis 162. The blade 160, or at least a supporting member therefor, is mounted on the yoke 166 for adjustment about a radial pitch axis 170, such adjustment serving to change the pitch of the blade.

For changing the pitches of the blades, each of them is provided with an arm 172 having an offset portion 174. A conventional rotary swash plate is provided with its axis coincident with the rotor axis, this plate being generally triangular and being shown schematically at 176. Substantially vertical links extend from the swash plate 176 to the offset portions 174 of the arms 172, one of said links being shown at 178. The swash plate 176 is movable vertically or angularly, in accordance with conventional practice, for collectively or cyclically changing the pitches of the blades by movement thereof about the pitch axes 170. Each link 178 and its connection with the corresponding arm 172 are preferably approximately in a vertical plane extending through the corresponding flapping axis 168. This arrangement eliminates or at least minimizes any pitch variations resulting from angular movements about said lag and flapping axes.

In accordance with the present invention an unbalance correcting mechanism is pro-

vided for each of at least two blades of the three-bladed rotor, the third blade being regarded as the master blade. It may be preferable to provide a correcting mechanism for each blade, as this permits any one of the several blades to be regarded as the master. The mechanism for the blade 160 is shown and the mechanism for the other blade or blades may be a duplicate of that shown. For purposes of explanation, the blade 160 may be regarded as a blade selected for adjustment to effect correction of unbalance.

The link 178 is not connected directly with the arm portion 174 but is connected indirectly therewith by means of an eccentric member 180. The arm portion 174 is bifurcated and a cylindrical opening extends transversely across the bifurcations. The member 180 extends into and fits the said opening and is rotatable therein. Said member 180 has a recess 182 at one side thereof and a pivot pin 184 extends across the recess. The upper end of the link 178 extends into the recess 182 in the member 180 and is connected with said pivot pin 184. Thus the link is connected at an axis that is eccentric of the central axis of the member 180. The member 180 has an upwardly extending arm 186 connected with a link 188 by means of which the member 180 may be moved rotatively. It will be seen that when the member 180 is turned in the clockwise direction the arm 172 is moved upwardly relatively to the pin 184 so as to decrease the pitch of the corresponding blade and to resultantly cause downward movement of the said blade about the flapping axis 168. When the member is turned in the counterclockwise direction the arm 172 is moved downwardly relatively to the pin 184 so as to increase the pitch of the corresponding blade and to resultantly cause upward movement of said blade about the flapping axis 168. It will be obvious that the described movement of the eccentric member 180 does not in any way affect the normal control of the blade pitch by the link 178.

For moving the link 188 and for thus effecting correction of unbalance, as explained, there is provided a mechanism which is carried by and rotatable with the rotor and which is adapted to be operated or controlled by nonrotatable means in the fuselage. When correction is effected by movement of a member such as 180 connected with the pitch control arm, said mechanism is preferably carried directly by said arm. As to details, the last said mechanism may be widely varied, but it may be substantially the same as the mechanism shown in Figs. 6 to 10 and already fully described. The mechanism, as shown, comprises an electrical actuator unit 86<sup>a</sup> and a gearing unit 88<sup>a</sup> similar respectively to the before-described units 86 and 88. These units are connected with the arm 172 at the

top thereof by any suitable means. A pivot arm 190 is provided which is similar to the previously described arm 90 except that it extends downwardly from its shaft instead of upwardly therefrom. The lower end of the arm 190 is pivotally connected with the link 188. It will be obvious that, when the mechanism is operated, the arm 190 is turned and the link 188 acts through the described mechanism to change the pitch of the blade and thereby move it upwardly or downwardly about the flapping axis for the purpose of effecting correction of unbalance.

The devices and circuit connections for controlling the last described correcting mechanism are not shown in detail, but they may be generally similar to those shown in Fig. 11 and described in connection therewith. When the rotor has three blades, there are correcting mechanism for each of at least two blades as previously stated, and there must be a separately operable control means for each said correcting mechanism.

Either with a helicopter of the type shown in Figs. 1 to 4 or with a helicopter of the type shown in Fig. 12, a condition of unbalance requiring correction may be usually determined by visually observing the paths of the tips of the rapidly rotating blades. Visual observation may be greatly facilitated by marking the tips of the blades with different colors. As an alternative to visual determination of unbalance, it is frequently possible for the pilot to feel the vibration resulting from the unbalance, correction then being made until the vibration is eliminated.

#### WHAT WE CLAIM IS:—

1. A helicopter comprising a fuselage and a substantially vertical rotor drive shaft connected with the fuselage and a rotor which includes at least two similar blades each having its inner portion connected with said shaft for movement about a substantially horizontal transverse axis, devices controlled from the fuselage for changing the pitches of all of rotor blades during rotation in accordance with flight requirements, a mechanism carried by the rotor for rotation therewith and adapted for correcting rotor unbalance which mechanism is connected with a selected blade of said rotor and is operable during rotor rotation for adjusting said selected blade to change the lift thereof relatively to that of each other blade while otherwise maintaining the pitches required for flight, control means for said correcting mechanism carried by said fuselage independently of said rotor, and means operatively connecting said control means on the fuselage with said correcting mechanism on the rotor for enabling said control means to control the operation of said mechanism during rotation of said rotor so as to separately adjust said connected blade in order to correct unbalance in said rotor.

2. A helicopter according to Claim 1, where-

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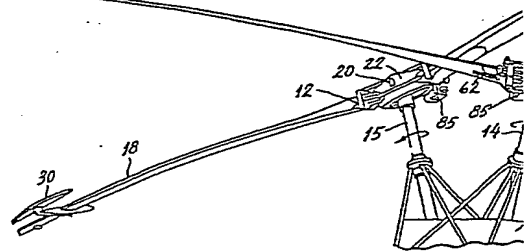
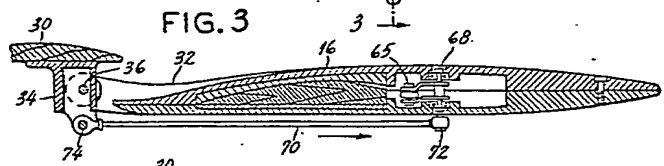
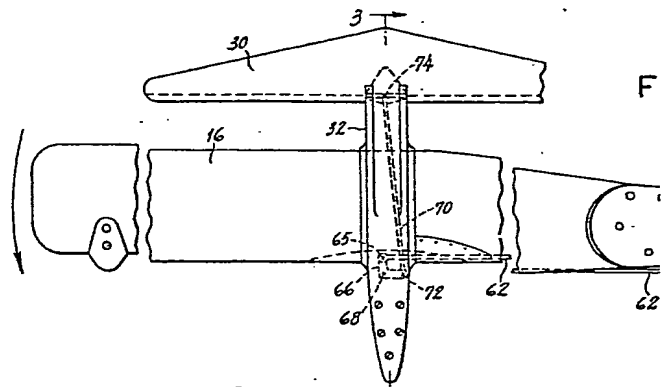
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- in the correcting mechanism is connected with the pitch changing devices and is operable during rotor rotation for changing the pitch of the selected blade relatively to the pitch of each other blade.
3. A helicopter according to Claim 2, wherein the rotor includes a hub to which the inner portion of each blade is connected and the selected blade has its outer or tip portion vertically adjustable relatively to said hub and each other blade in connection with the independent pitch adjustment.
4. A helicopter according to Claim 3, wherein the pitch changing devices include a bell crank lever connected by links to the correcting mechanism so that the axis of said bell crank is movable to adjust the pitch of said selected blade.
5. A helicopter according to Claim 3 or 4, wherein the hub is pivoted on the shaft so that said hub and correcting mechanism oscillate about a substantially horizontal reter axis.
6. A helicopter according to Claim 3, 4 or 5, wherein each blade is connected with the hub for relative movement about a substantially vertical lead-lag axis, and the correcting mechanism is connected with the selected blade for movement in unison with said blade about the corresponding lead-lag axis.
7. A helicopter according to any one of Claims 3 to 6, wherein the blades have substantially vertical lead-lag hinge pins secured thereto connecting them with the hub for relative movement about the axes of said pins, and wherein the correcting mechanism is carried by the lead-lag hinge pin for the selected blade and movable with said lead-lag hinge pin.
8. A helicopter according to any one of the preceding claims, wherein the correcting mechanism includes an electric actuator controlled by the control means which is electrical and carried by the fuselage independently of said rotor, and electrical conductors between the control means and the actuator enabling the former to control the operation of the latter during rotation of the rotor.
9. A helicopter according to any one of Claims 4 to 8, wherein each blade is provided with a servo flap for the angular adjustment for aerodynamic change of the pitch, and each said flap being operable by the correcting mechanism for the independent adjustment.
10. A helicopter according to Claim 9, wherein each flap is connected with the links and the lever to effect the pitch adjustment.
11. A helicopter substantially as hereinbefore described and as illustrated in the accompanying drawings.
- STEVENS, LANGNER, PARRY &  
ROLLINSON,  
Chartered Patent Agents,  
Agents for the Applicants.

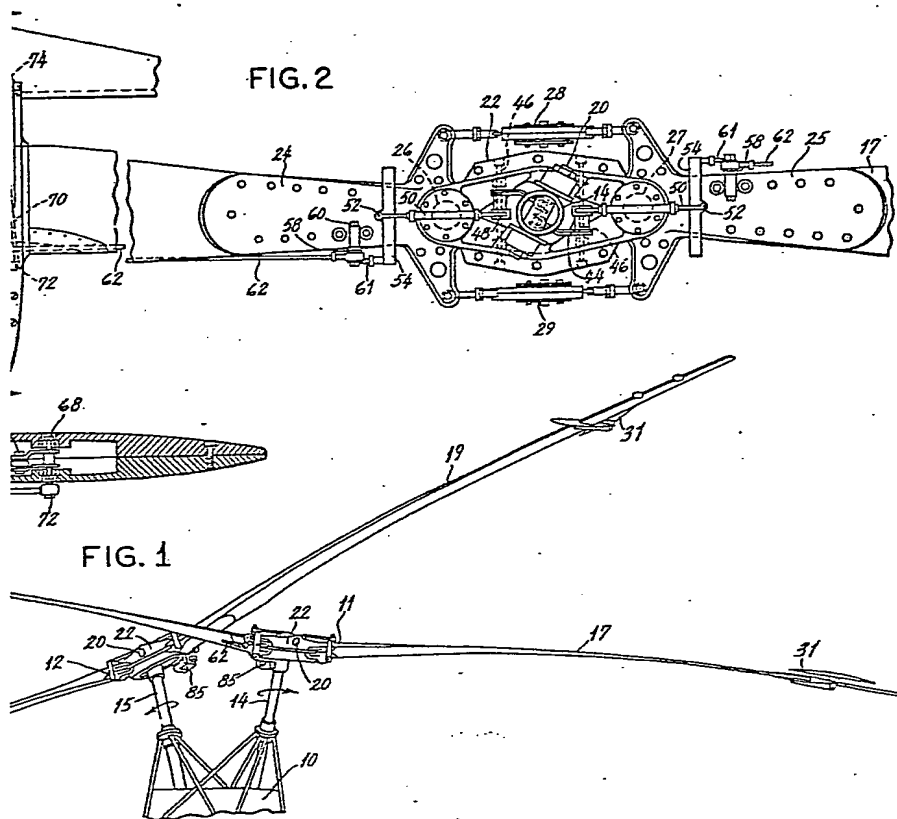


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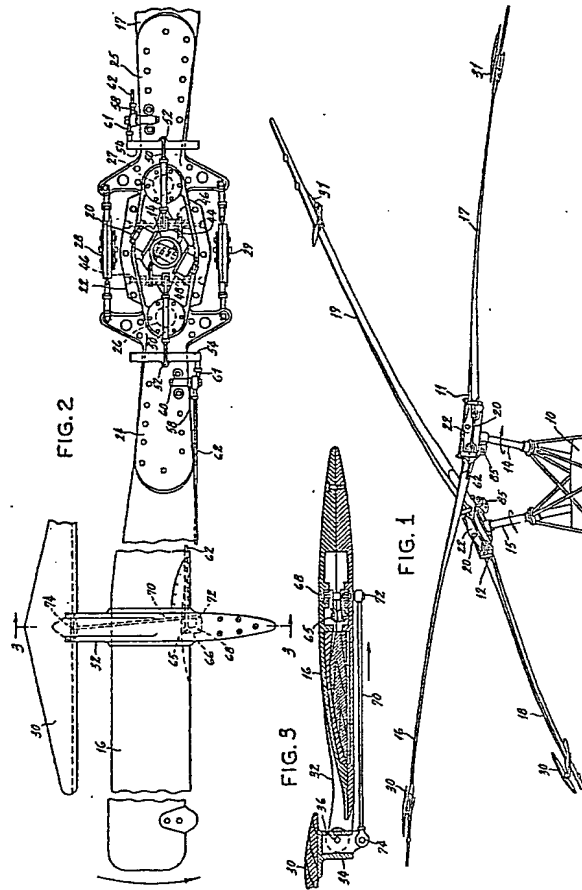


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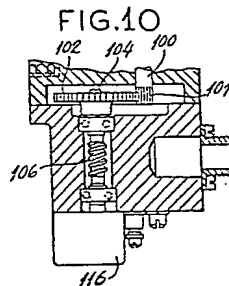
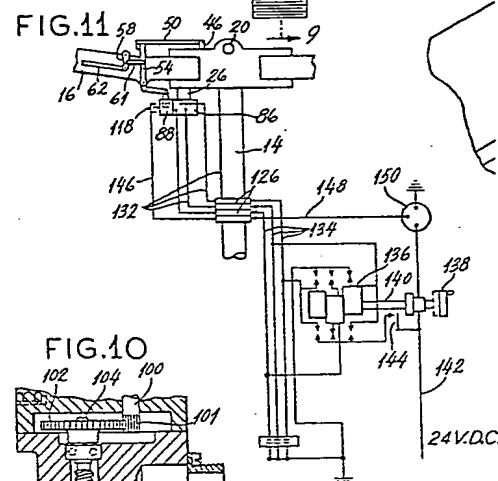
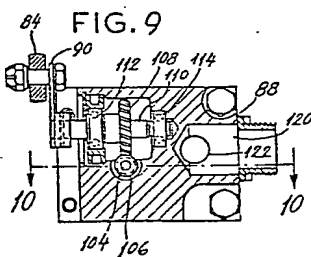
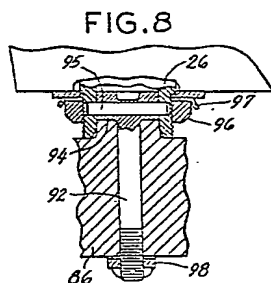
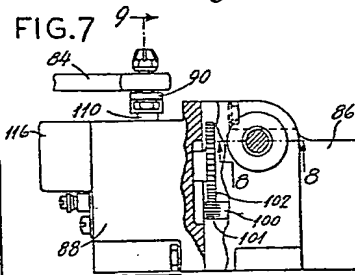
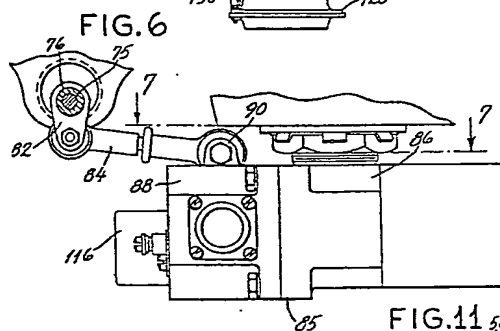
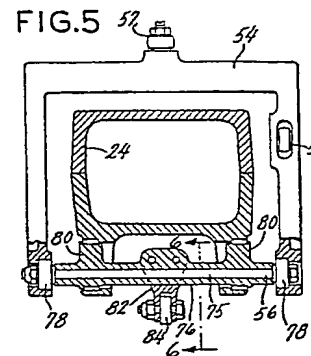
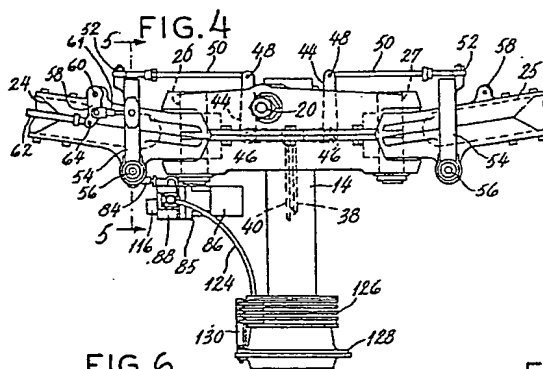
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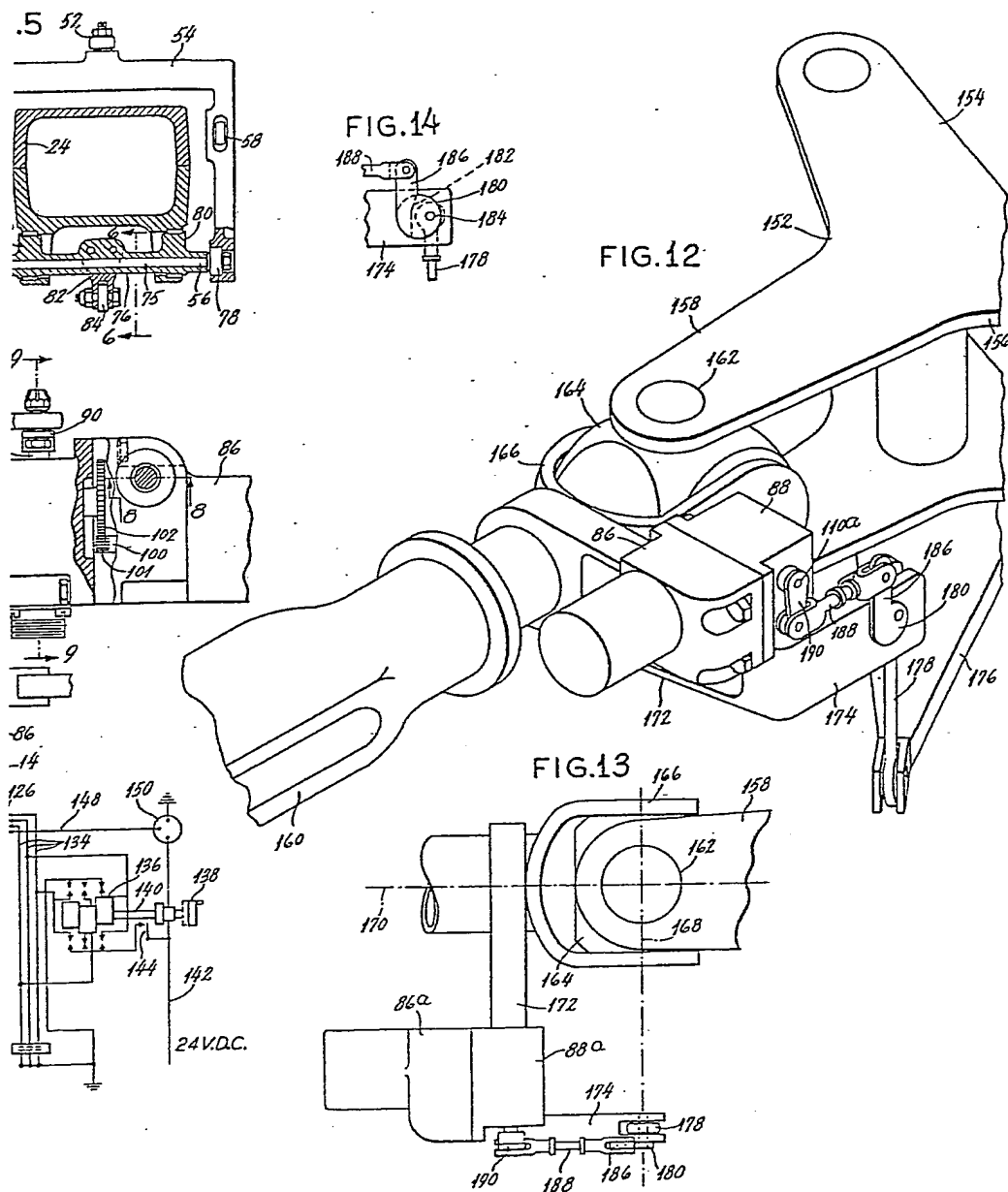


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